Introduction

Project Introduction and Background

When measured using proper equipment in a lab, EEG signals can accurately represent brain activity. Clinically, EEG data are useful for diagnosing brain disorders such as epilepsy, and as a tool for studying sleep. In other realms of brain research, EEGs are used as an alternative to technologies like fMRIs and PET scans as a way to visualize the brain's internal processes. The NeuroSky MindSet is a commodity EEG that is available cheaply and claims to measure brain signals by means of three electrodes located on the ear and temple. Its output is purported to be useful in determining the state of the brain, especially with respect to levels of concentration and relaxation. This technology should enable advances in research areas such as education, in which an understanding of students' focus levels could prove highly valuable when teaching or designing curricula. We attempt to explore some of these possibilities by analyzing EEG data collected in the course of a variety of activities and attempting to algorithmically distinguish between them in MATLAB.

A Brief Overview of the Device

The MindSet package consists of the headset itself, a charging cable, a Bluetooth dongle, and a collection of software (mostly games) intended to demonstrate the functionality of the device. The device communicates all of its data to the computer over a Bluetooth connection. This package is sold by NeuroSky for $200. The encoding of this Bluetooth serial data is such that it is not human readable, and is difficult to parse in software. Because of this, it is necessary to purchase an additional research package in order to collect and analyze the headset's raw data. NeuroSky calls this package the "MindSet Research Tools (MRT)," and sells it for $500. The MRT includes two applications for collecting and analyzing data from the MindSet: a simpler one called NeuroView, and a more complex one called NeuroSkyLab. NeuroView provides a simple interface for recording data from the headset and saving it in a format that can be easily loaded into MATLAB. NeuroSkyLab allows more analysis to be done inside the application environment, however we chose do do all of our analysis in MATLAB. Because we had no need for this functionality outside of MATLAB, we chose to use the cleaner NeuroView interface to collect data.

Once loaded into the MATLAB environment, all of the data can of course be analyzed using standard techniques in signal processing.

Experimental Methods
A description of the experiments and methods used in the project.

Experimental Methods
The overall goal of the experiment was to develop an algorithmic way to differentiate between the spectrograms of various mental activities. The following section details the approach to achieving this goal:

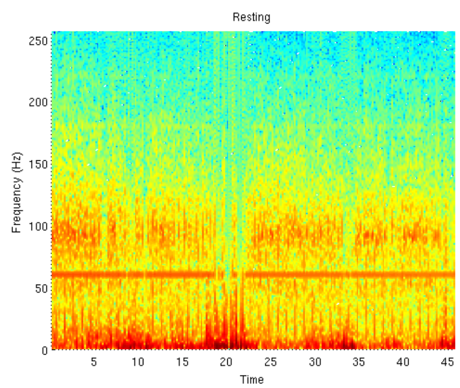
Data was collected using the Neurosky Mindset. The Mindset is a commercial-grade EEG used widely in education and academic research. It measures 'brainwaves', the aggregate charge of hundreds of thousands neural discharges, through use of a dry-electrode that can sense electrical activity. The electrode is placed on the forehead and the device is connected to a computer via Bluetooth for data collection. The electrode returns the voltage and an associated time stamp so that a time versus voltage plot can be generated over the sample period. From these data, a Fourier transform is taken, enabling analysis in the frequency domain. In addition, the power spectral density of the data was taken to determine at which frequencies the most activity was occurring.

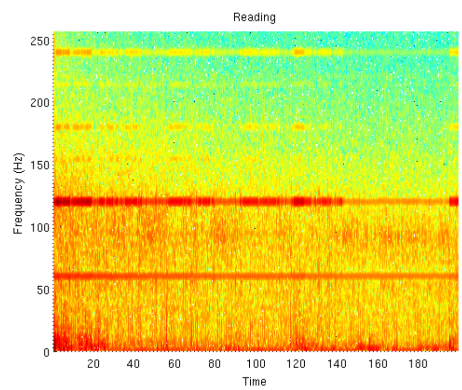
To find out whether or not changes in mental state could be resolved using the data collected from the Mindset, multiple experiments were designed. Different activities that required 'concentration' were selected to see if they could be differentiated from their respective spectrograms, as well as a couple of 'relaxation' activities.

The activities that required concentration were chosen to be disparate so that their spectrograms would hopefully reveal common traits across all people when doing the same activity but have noticeable differences across different activities. Mental arithmetic, reading, and listening to music were the chosen activities in this regard. For all of the tests, the Mindset was placed on the subject's head and data collection was started as soon as the activity was commenced. The mental arithmetic test involved a taking a quiz of simple math problems. The quiz consisted of basic arithmetic operations (addition, subtraction, division, and multiplication) as well as some simple word and figure problems (for example, if you see a car moving from left to right in your rearview mirror, in which direction will it be moving to someone who is facing your car?). The reading experiment

simply had the test subjects read an interesting article from beginning to end. For the music test, the subject listened to two very different pieces of music, a Beethoven composition and a heavy metal song. Not only was the goal to differentiate between separate activities in this case, but also to see if a distinction could be made within the same activity between two pieces from the spectrogram.

Example: Resting and Reading Spectrograms





There were two forms of relaxation activities. The first simply was a period of data collection while the subject sat at rest. In the second activity, the subject first listened to 'Binaural Beats'. This piece of music was designed to induce a sense of deep relaxation in the user through use of extremely low frequency sounds. After listening to the beats, the user then relaxed while data was collected through the Mindset. The purpose of running these tests was to not only see if a base pattern characterizing relaxation could be established in the spectrograms, but also to see if there was any significance in the spectrograms when the subject was in a 'deep' meditation.

Later tests combined both the relaxation and mental activities into one session in order to eliminate experimental error from non-constant electrode positioning and factors affecting mental state at different times. It also makes heuristically differentiating between 'relaxing' and 'concentrating' much easier when both activities are represented on a single spectrogram. The subject would first relax for a period of one minute and then start the 'concentration' activity.

All of the experiments were conducted on the four members of the group, with multiple trials ran for each individual.

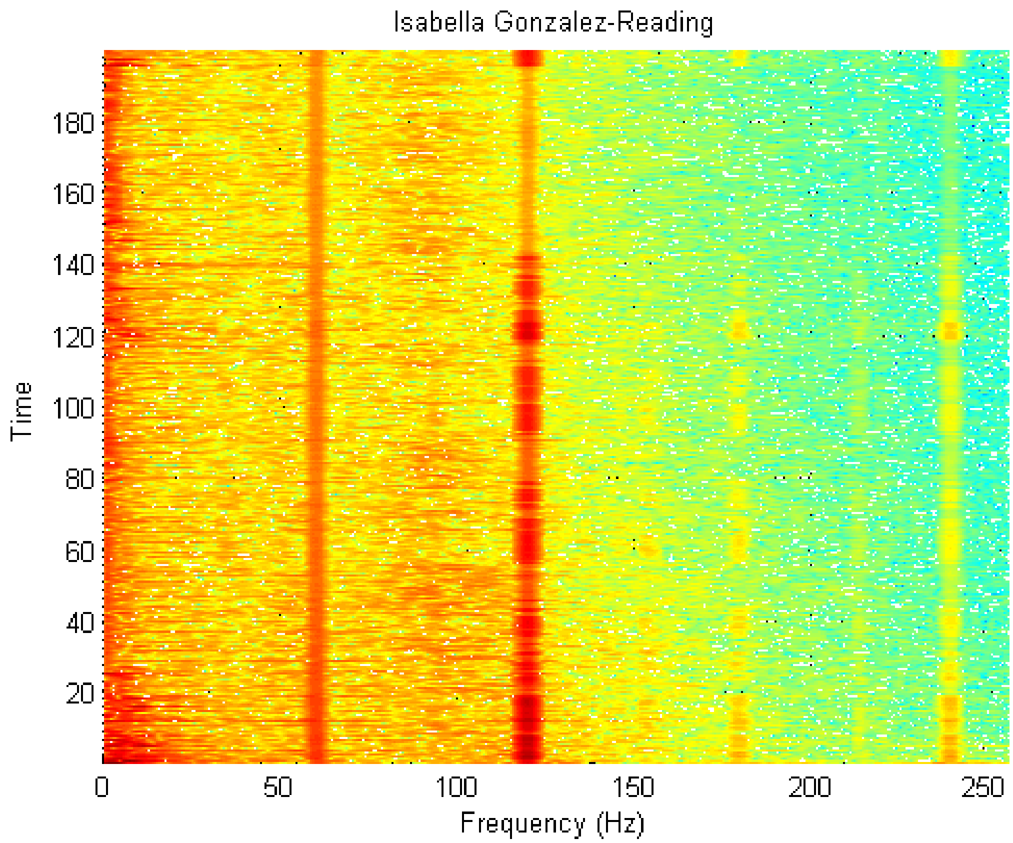
From the results of the experiment, it was apparent that the reading and simple relaxation activities returned the most consistent and useful data. Due to this fact, the algorithm to differentiate between different mental activities was designed around these experiments.

Methods of Analysis

Spectrogram and PSD

From the Neurosky Mindset we could gather data points in the time domain. Given this information though, we could not discern any differences between our experiments. Thus, we decided to analyze our data in the frequency domain using Matlab.

The Matlab function Spectrogram segments a time domain signal and for each segment calculates the fourier transform of each segment. The function produces a graphic much like the following:

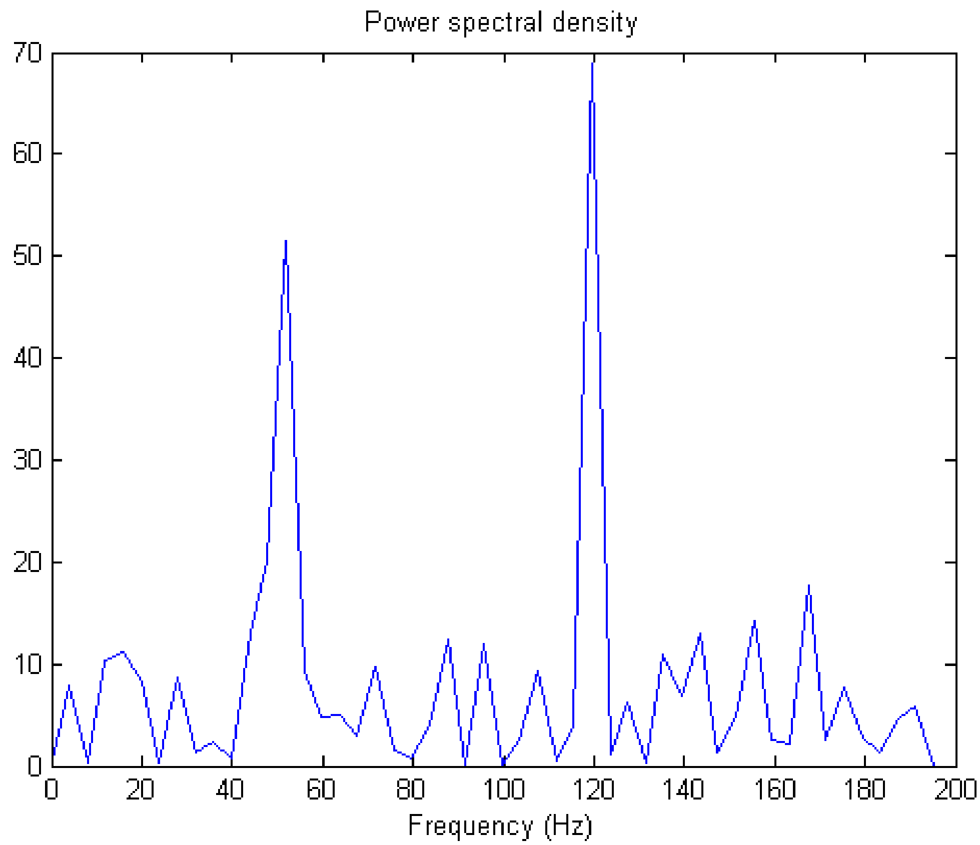


As one can see, at each time there is some frequency distribution, where red corresponds to a relatively large value and blue corresponds to a relatively small value.

The inputs to the function are the sampling frequency and the specific window. We set the sampling frequency to 512 since Neurosky samples at

512 HZ. We let the window be a hamming window because it seems to be the most widely used window for basic fourier analysis. We chose window size to be .4 seconds (200 samples) empirically based on how nice our figures looked.

The second function we used in Matlab was the Power spectral density (PSD) function. This function finds the average power at each frequency.



Both these methods gave us effective ways to find differences in our experimental data.

Algorithm for Differentiating Between Mental Activities
In this section are a description of how we processed raw EEG data, as well as an overview of how we algorithmically distinguished between the data associated with resting and reading.

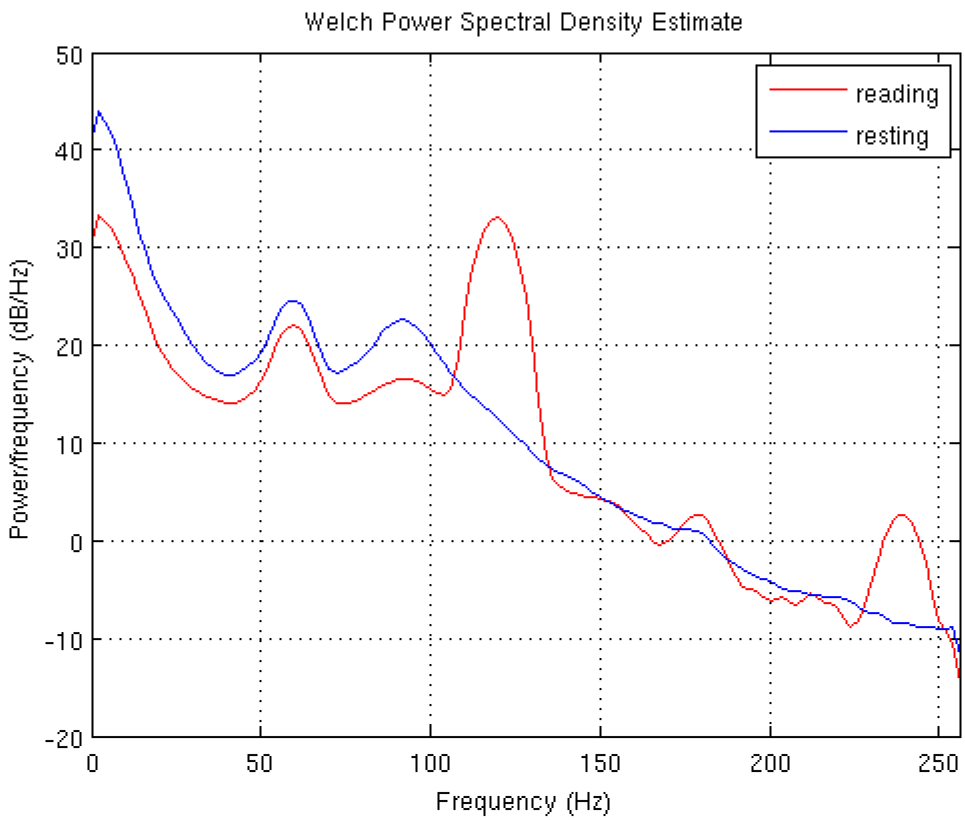
The Algorithm

After collecting a large amount of data related to different activities and, in theory, different levels of brain activity, we attempted to make general statements about the differences between them. Nearly all of the data we collected revealed that distinct activities resulted in distinct brain signals; however, some of these differences appeared more reliably and more markedly than others. By examining the spectrograms we created for each scenario, we determined that relaxing and reading were two of the most distinct activities with respect to measured brain activity. With this in mind, we decided to design and implement an algorithm capable of distinguishing between spectrograms associated with relaxing or reading.

The initial step in this process was an analysis of the spectrograms and power spectral density plots collected for different trials of reading and resting. Several features seemed potential candidates to be leveraged in the algorithm. One striking difference is the presence of an intense band of activity at 120 Hz, which appears in the reading spectrogram but is absent in the resting spectrogram. Despite its stark differences, we chose not to incorporate this feature into the algorithm because we felt that it does not likely indicate a true effect occurring in the brain. Rather, its ubiquity across many of our measurements (and the fact that its frequency never wavers) led us to believe that it might be an artifact of the headset. Instead, we were more interested in the fact that the resting state appears to have more energy just above baseband, in the 10-50 Hz range. Ultimately, this was the feature we selected for in the algorithm. Because this is an effect that accumulates over the entire period of the experiment, the Power Spectral Density plot provides an excellent way to quantify these differences. As is evident in the PSD plot below, the intuitions we developed from the spectrograms are clearly confirmed to hold true for the example below. After inspecting several other trials, we decided that the 10-50 Hz frequency range selected the phenomenon we observed while excluding potential sources of noise like 60 Hz noise. Thus, we wrote a script to integrate the power in this

range for the two sets of data. It then attributes the higher value to the resting state and the lower to a reading state. With the appropriately set integration limits. the algorithm correctly determined the source of the data for all of the trials we performed.

A PSD Comparison of Reading and Resting



Future Direction

Potential Improvements upon Research

- Different windowing techniques
- Analysis of distribution of data values. Maybe different experiments produce different distributions of data?
- Discern between activities that require focus
- Compare our Neurosky Data to laboratory EEG data

Implications

We found that at some basic level we can use Neurosky Data to figure out what mental activities one is carrying on. After further research maybe one could associate certain frequency distributions that correspond to focus in a very. Then maybe one could association levels of focus to difficulty of problems. Perhaps, maybe if a problem is too hard, one loses focus, and maybe has less of a learning experience.

In addition, it is likely possible that real-time system could be implemented that would aid in the teaching process. For example, if everyone were wearing a Neurosky headset, then the teacher could see how certain concepts are catching the class’s focus or lack thereof.

Conclusion

Using the NeuroSky Mindset device and the algorithm that we developed, we are can successfully distinguish when a person is relaxing and when the same person is focusing (while reading, for example). To differentiate the mental states of the subject, we relied on measurements from the power spectral density within the 10-50 Hz range. We integrated the power over these frequencies rather than calculating the L_∞norm on the PSD because measurements with a very large variance in energy could be classified as the wrong mental state. The relaxing state in general showed a higher value than the reading state, and this trend was the basis of the algorithm to detect whether a subject was concentrating or not.

Although the results indicated an increase in energy at the harmonic frequencies 60 and 120 Hz while the subject was reading, we determined these are probably artifacts from the device and could not be used as a metric for concentration alone. Despite all the different subjects and trials, the spectrograms never showed any variation in frequency from these 60 and 120 Hz peaks.

The device had several shortcomings as an EEG that limited the experiments we wanted to perform. The NeuroSky MindSet uses a single, dry sensor. The position on the head is not standard for all the users and the relationship between placement of this sensor on different parts of the forehead and its effects on the measurements are not well understood. In the future, it would be helpful to compare the results to results collected using an EEG cap used in supervision of a medical professional.